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CHARACTERIZING IONIZATION AND ELECTRON DYNAMICS IN BIOLOGICAL MATERIALS: THEORETICAL AND NUMERICAL INSIGHTS INTO PULSED LASER-INDUCED BREAKDOWN PROCESSES

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Abstract. This research presents an analysis of free electron generation in biological materials subjected to intense laser radiation. The study significantly deepens the existing models by integrating a range of ionization mechanisms - photoionization, cascade ionization, thermal ionization, and chromophore ionization - alongside a detailed consideration of electron diffusion, attachment, and recombination kinetics. The model also introduces quantum mechanical considerations to address the energy state transitions and sub-atomic interactions within the material, which are crucial for accurately predicting ionization outcomes. Additionally, non-linear optical phenomena such as multiphoton absorption and the Kerr effect are incorporated to assess their influence on the overall ionization process and the spatial-temporal distribution of free electrons. The accuracy and applicability of the model are further enhanced by systematically varying external laser parameters - wavelength, pulse duration, and pulse energy - and examining their effects in conjunction with the intrinsic optical properties and surface characteristics of the biological materials. This approach allows for a precise manipulation of the laser-material interaction to achieve desired modification outcomes. The model's predictions are validated against a range of experimental data, including recent developments in time-resolved spectroscopy that provide a high-resolution view of electron dynamics. This validation not only confirms the model's robustness but also identifies areas for parameter optimization to improve the efficiency and precision of laser applications in biological media. This research thus extends the fundamental understanding of laser-material interactions, providing a solid foundation for further developments in medical and biotechnological applications.

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